Transverse energy distributions and J/ψ production in Pb+Pb collisions

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We have analyzed the latest NA50 data on transverse energy distributions and J/ψ suppression in Pb+Pb collisions. The transverse energy distribution was analysed in the geometric model of AA collisions. In the geometric model, fluctuations in the number of NN collisions at fixed impact parameter are taken into account. Analysis suggests that in Pb+Pb collisions, individual NN collisions produces less $< E_T >$, than in other AA collisions. The nucleons are more transparent in Pb+Pb collisions. The transverse energy dependence of the J/ψ suppression was obtained following the model of Blaizot et al, where charmonium suppression is assumed to be 100% effective above a threshold density. With fluctuations in number of NN collisions taken into account, good fit to the data is obtained, with a single parameter, the threshold density.

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In relativistic heavy ion collisions J/ψ suppression has been recognized as an important tool to identify the possible phase transition to quark-gluon plasma. Because of the large mass of the charm quarks, $c\bar{c}$ pairs are produced on a short time scale. Their tight binding also make them immune to final state interactions. Their evolution probes the state of matter in the early stage of the collisions. Matsui and Satz [1] predicted that in presence of quark-gluon plasma (QGP), binding of $c\bar{c}$ pairs into J/ψ meson will be hindered, leading to the so called J/ψ suppression in heavy ion collisions [1]. Over the years several groups have measured the J/ψ yield in heavy ion collisions (for a review of the data and the interpretations see [2,3]). In brief, experimental data do show suppression. However this could be attributed to the conventional nuclear absorption, also present in pA collisions.

The latest data obtained by the NA50 collaboration [4] on J/ψ production in Pb+Pb collisions at 158 A GeV is the first indication of anomalous mechanism of charmonium suppression, which goes beyond the conventional suppression in nuclear environment. The ratio of J/ψ yield to that of Drell-Yan pairs decreases faster with E_T in the most central collisions than in the less central ones. It has been suggested that the resulting pattern can be understood in a deconfinement scenario in terms of successive melting of charmonium bound states [4].

In a recent paper Blaizot et al [5] showed that the data can be understood as an effect of transverse energy fluctuations in central heavy ion collisions. Introducing a factor $\varepsilon = E_T/E_T(b)$ and assuming that the suppression is 100% above a threshold density (a parameter in the model) and smearing the threshold density (at the expense of another parameter) best fit to the data was obtained. Capella et al [6] analysed the data in the comover approach. There also, the comover density has to be modified by the factor ε. Introduction of this adhoc factor ε can be justified in a model based on excited nucleons represented by strings [7].

At a fixed impact parameter, the transverse energy as well as the number of NN collisions fluctuate. The Fluctuations in the number of NN collisions were not taken into account in the calculations of Blaizot et al [5] or in the calculations of Capella et al [6]. In the present paper, we present a calculation following the model of Blaizot et al [5] which includes these fluctuations. As will be shown below, if the fluctuations in number of NN collisions are taken into account very good description of the NA50 data can be obtained without smearing the threshold density. The smearing effect is generated by the fluctuations.

Geometric model has been quite successful in explaining the transverse energy production as well as multiplicity distributions in AA collisions [8,9]. In this model, it is assumed that at impact parameter $\mathbf{b}$, the number n of NN collisions is Poisson distributed with average $< n_b >$. In the Glauber approximation $< n_b >$ is written as,,

$$< n_b >= \sigma_{NN} \int d^2 s T_A(\mathbf{s}) T_B(\mathbf{s}-\mathbf{b}) \tag{1}$$

where σ_{NN} is the inelastic NN cross-section, assumed to be 32 mb. In this model all the nuclear information is contained in the nuclear thickness function is $T_{A,B}(\mathbf{s}) = \int dz \rho_{A,B}(\mathbf{s},z)$. In the present calculation, we have used the following parametric form for $\rho_A(r)$ [5],

$$\rho_A(r) = \frac{\rho_0}{1+exp(\frac{r-r_0}{a})} \tag{2}$$

with a=0.53 fm, $r_0 = 1.1A^{1/3}$. The central density is obtained from $\int \rho_A(r) d^3 r = A$.

In the geometric model, the probability to obtain E_T at impact parameter $\mathbf{b}$ in n- number of NN collisions is written as,

$$P_n(b, E_T) = \frac{e^{-<n_b>} < n_b >^n}{\Gamma(n+1)} Q^{\{n\}}(E_T) \tag{3}$$

where $Q^{\{n\}}(E_T)$ is the n-fold convolution of E_T distribution resulting from elementary NN collisions,

$$Q^{\{n\}}(E_T) = \int dE_T^1 ... dE_T^n g(E_T^1)...g(E_T^n) \times \delta(E_T - E_T^1 ... - E_T^n) \tag{4}$$

In eq.4 $g(E_T)$ is the normalized E_T distribution for NN collisions. Most of the E_T distributions in NN collisions can be well approximated by the gamma distribution,

$$g(E_T) = \frac{\alpha^\beta}{\Gamma(\beta)} e^{-\alpha E_T} E_T^{\beta - 1} \tag{5}$$

with the parameters α and β. For the gamma distribution, the average and the variance are,

$$< E_T >_{NN} = \beta/\alpha \tag{6a}$$

$$< E_T^2 > / < E_T >^2 - 1 = 1/\beta \tag{6b}$$

Gamma distribution has an elegant convolution property which greatly facilitate computation. n-fold convolution of a gamma distribution is again a gamma distribution, with parameters $\alpha' = \alpha$ and $\beta' = n\beta$. Thus,

$$Q^{\{n\}}(E_T) = \frac{\alpha^{n\beta}}{\Gamma(n\beta)} e^{-\alpha E_T} E_T^{n\beta - 1} \tag{7}$$

The final transverse energy distribution is then obtained from eq.3 by summing it over n (from 1 to ∞) and averaging over the impact parameter $\mathbf{b}$.

Geometric model has been quite successful in explaining the E_T distributions in heavy ion collisions with $\alpha \sim 2$ and $\beta \sim 2$ [9]. We have fitted the E_T distribution in Pb+Pb collisions varying the parameter α and β. NA50 collaboration did not correct the E_T spectra for the efficiency of target identification algorithm, which is lower than unity for E_T lower than 60 GeV. To obtain the parameters α and β we have fitted the purely inclusive part of the E_T spectra ($E_T > 60$ GeV). Very good fit to the data is obtained with $\alpha = 3.46 \pm .19$ and $\beta = 0.379 \pm 0.021$. The fit is shown in fig.1. We note that best fitted values of α and β indicate that average E_T produced in individual NN collisions is order of magnitude smaller than in other AA collisions [9]. The variance is also a order of magnitude large. It seems that the nucleons are more transparent in Pb+Pb collisions than in (say) O+Au collisions, leading to less $< E_T >$ in individual NN collisions. It is evident that E_T production mechanism in Pb+Pb collisions is different from other AA collisions. Transparency of nucleons in Pb+Pb collisions may be interpreted as an indication of QGP production in Pb+Pb collisions.

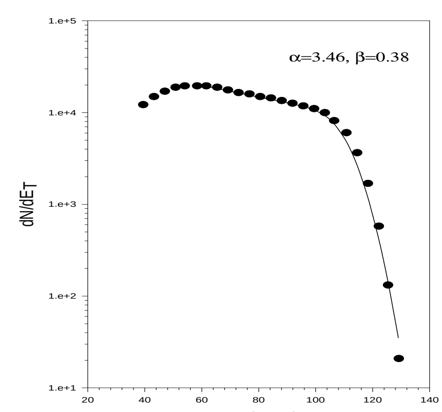

FIG. 1. Transverse energy distribution in Pb+Pb collisions

As mentioned in the beginning, we have followed the model of Blaizot et al [5] to analyze the E_T dependence of charmonium suppression. Charmonium production cross-section at impact parameter $\mathbf{b}$ is written as,

$$d^2\sigma^{J/\psi}/d^2b = \sigma^{J/\psi} \int d^2 s T_A^{eff}(\mathbf{s}) T_B^{eff}(\mathbf{s}-\mathbf{b}) S(\mathbf{b},\mathbf{s}) \tag{8}$$

where $T_{A,B}^{eff}$ is the effective nuclear thickness function,

$$T^{eff}(\mathbf{s}) = \int_{-\infty}^{\infty} dz \rho(\mathbf{s},z) exp(-\sigma_{abs} \int_z^{\infty} dz' \rho(\mathbf{s},z')) \tag{9}$$

with σ_{abs} as the cross-section for J/ψ absorption by nucleons. The exponential factor is the nuclear absorption survival probability, the probability for the $c\bar{c}$ pair to avoid nuclear absorption and form a J/ψ. $S(\mathbf{b},\mathbf{s})$ is the anomalous part of the suppression. Blaizot et al [5] assumed that J/ψ suppression is 100% effective above a threshold density (n_c), a parameter in the model. Accordingly the anomalous suppression part was written as,

$$S(\mathbf{b},\mathbf{s}) = \Theta(n_c - n_p(\mathbf{b},\mathbf{s})) \tag{10}$$

where n_p is the density of participant nucleons in impact parameter space,

$$n_p(\mathbf{b},\mathbf{s}) = T_A(\mathbf{s})[1 - e^{-\sigma_{NN} T_B(\mathbf{b}-\mathbf{s})}] + [T_A \leftrightarrow T_B] \tag{11}$$

Recognizing that the endpoint behavior of charmonium suppressions are due to transverse energy fluctuations, Blaizot et al [5] modified the density of participant nucleons by a factor $\varepsilon = E_T/E_T(b)$. This modification makes sense only when n_p is assumed to be proportional to the energy density. Implicitly it was also assumed that the E_T fluctuations are strongly correlated in different rapidity gaps. The assumption was essential as NA50 collaboration measured E_T in the 1.1-2.3 pseudorapidity window while the J/ψ's were measured in the rapidity window $2.82 < y < 3.92$ [4]. In the geometric model, strong correlation between E_T fluctuations in different rapidity window is readily obtained. At a fixed impact parameter, fluctuations in E_T can be calculated as [9]

$$\frac{<E_T^2>_{AA} - <E_T>_{AA}^2}{<E_T>_{AA}^2} = \frac{<N^2> - <N>^2}{<N>^2} + \frac{1}{<N>} \frac{<E_T^2>_{NN} - <E_T>_{NN}^2}{<E_T>_{NN}^2} \tag{12}$$

The E_T fluctuations has two parts, (i) geometric in nature which remains same irrespective of rapidity window, (ii) which depend on fluctuations in the E_T distributions in NN collisions. The 2nd part changes with rapidity window but its effect is less as it is weighted by the factor $1/<N>$. Fluctuations of E_T in different rapidity windows are thus strongly correlated.

We calculate the J/ψ production as a function of transverse energy, at an impact parameter $\mathbf{b}$ as,

$$d\sigma^{J/\psi}/dE_T = \sum_{n=1}^{\infty} P_n(b,E_T) P(\psi \mid E_T,\mathbf{b}) \tag{13}$$

where $P_n(b,E_T)$ is the probability to obtain E_T in n NN collisions (eq.(3)) and $P(\psi \mid E_T,\mathbf{b})$ is the probability to produce a charmonium with transverse energy E_T. $P(\psi \mid E_T,\mathbf{b})$ is given by eq.8, with anomalous suppression part modified according to,

$$S(\mathbf{b},\mathbf{s}) = \Theta(n_c - \frac{E_T}{n\beta/\alpha} n_p(\mathbf{b},\mathbf{s})) \tag{14}$$

where we have replaced $E_T(b)$ by $n\beta/\alpha$ appropriate in the geometric model. This modification takes into account the fluctuations in number of NN collisions at fixed impact parameter $\mathbf{b}$.

The Drell-Yan production was calculated similarly, replacing $P(\psi \mid E_T,\mathbf{b})$ in eq.13 by the Drell-Yan production cross-section,

$$d^2\sigma^{DY}/d^2b = \sigma^{DY} \int d^2 s T_A(\mathbf{s}) T_B(\mathbf{s}-\mathbf{b}) \tag{15}$$

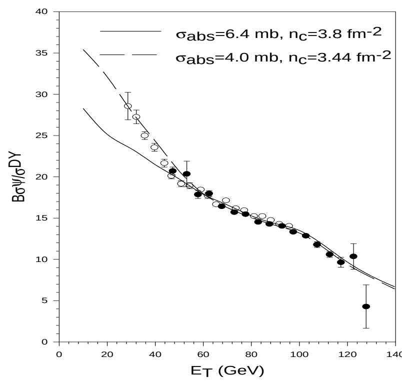

FIG. 2. J/ψ survival probability in Pb+Pb collisions as a function of transverse energy.

In fig.2, we have compared the theoretical charmonium production cross-section with NA50 experimental data. The normalization factor $\sigma^{J/\psi}/\sigma^{DY}$ was taken to be 53.5. The solid curve is obtained with σ_{abs}=6.4 mb, and $n_c = 3.8 fm^{-2}$. Very good description of the data from 40 GeV onward is obtained. It may be noted that if the fluctuations in the NN collisions were neglected, equivalent description is obtained with threshold density $n_c = 3.75 fm^2$, with smearing of the Θ function at the expense of another parameter. It is evident that in this model, the smearing is done by fluctuating NN collisions. Theoretical calculations predict more suppressions below 40 GeV, a feature evident in other models also. It is possible to fit the entire E_T range, reducing the J/ψ-nucleon absorption cross-scetion. The dashed line in fig.2, corresponds to σ_{abs}=4 mb and $n_c = 3.42 fm^{-2}$.

To summarize, we have analysed the transverse energy distribution in Pb+Pb collisions as well as the charmonium production data obtained by the NA50 collaboration. The transverse energy distribution was analysed in the geometric model. It was seen that in order to fit the experimental data, individual NN collisions are required to produce (on the average) less E_T, compared to other AA collisions. It seems that in Pb+Pb collision, the nucleons become transparent. The charmonium production data was analysed following the model of Blaizot et al [5], including the effect of fluctuations in number of NN collisions at fixed impact parameter. The experimental data from 40 GeV onwards could be very well fitted with σ_{abs}=6.4 mb and a threshold density of 3.8 fm^{-2}. Neglecting the fluctuations in number of NN collisions, equivalent fit could only be obtained by smearing the Θ function at the expense of an added parameter. Data in the entire E_T range could be fitted reducing the J/ψ-nucleon absorption cross-section to σ_{abs}=4 mb. The threshold density is also reduced to 3.44 fm^{-2}. Considering that nucleons become more transparent (as suggested by the E_T data), such a reduction seems plausible. Melting of charmoniums above a threshold density as well as apparent transparency of nucleons (as evident from analysis of E_T distribution) strongly suggests that in Pb+Pb collisions, QGP like environment is produced.

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[1] T. Matsui and H. Satz, Phys. Lett. B178,416(1986).
[2] R. Vogt, Phys. Reports, 310, 197 (1999)
[3] C. Gerschel and J. Hufner, Ann. Rev. Nucl. Part. Sci. 49, 255 (1999).
[4] NA50 collaboration, Phys. Lett. B 477,28(2000)
[5] J. P. Blaizot, P. M. Dinh and J.Y. Ollitrault, Phys. Rev. Lett. 85,4012(2000).
[6] A. Capella, E. G. Ferreiro and A. B. Kaidalov, hep-ph/0002300, Phys. Rev. Lett. 85,2080 (2000).
[7] J. Hufner, B. Kopeliovich and A. Polleri, nucl-th/0012003.
[8] A. K. Chaudhuri, Nucl. Phys. A515,736(1990).
[9] A. K. Chaudhuri, Phys. Rev. C47,2875(1993).